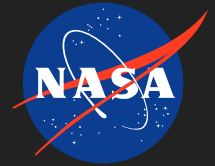


Sensorimotor Displays and Controls to Enhance the Safety of Human/Machine Cooperation During Lunar Landing

Completed Technology Project (2008 - 2012)



Project Introduction

Landing on the moon or another planetary body requires the selection and identification of an appropriate location that is level and free of hazards, along with a stable controlled descent to the surface. During crewed landings astronauts normally interact with automated systems, based upon terrain maps and sensor updates, to perform tasks such as manual re-designation of the landing point, adjustment of the automatic descent trajectory, or direct manual control. However, various sensorimotor challenges may interfere with the astronauts' responses. These include the astronauts' first exposure to partial gravity following microgravity adaptation, unique vehicle motions, and dust blowback from the descent engine thruster. This collaborative project is led by Prof. Laurence Young of Massachusetts Institute of Technology (MIT), assisted by collaborators at MIT, Draper Laboratory, NASA Johnson Space Center (JSC), and the U.S. Army Aeromedical Research Laboratory. The project has four specific aims: (1) Examine the nature of anticipated sensorimotor difficulties as they affect the transition from automatic to manual control; (2) Develop and evaluate advanced display countermeasures for enhancing situation and terrain awareness and for overcoming performance limitations caused by the reduced visibility associated with lunar lighting, terrain reflectivity, and the absence of atmosphere, utilizing Draper Laboratory's fixed-base lunar lander cockpit simulator for full human-in-the-loop evaluation; (3) Evaluate the effectiveness of the cockpit displays during human-in-the-loop manual control in the JSC Tilt-Translation Sled (TTS) during critical and hover tasks testing the tilt-translation and tilt-gain illusions of altered acceleration sensitivity as it applies to lunar gravity following a period of weightlessness; and (4) Evaluate the displays and the visual challenges of lunar landing using the Draper simulator, the JSC TTS and the U.S. Army Aeromedical Research Laboratory's six-degree-of-freedom helicopter simulator.

During the fourth year, the project has progressed along several lines. At NASA JSC, our advanced countermeasure prototype displays have been implemented, as well as a simulated out-the-window view of the lunar surface. We utilized the TTS to simulate two vehicle pitch attitude responses – 1) basic Tilt-Translation Sled and 2) Lunar Lander Vehicle – a single first-order divergent controlled element model with two inceptor sensitivity gains. The vehicle dynamics were approximated as a divergent (positive feedback for the critical tracking task) first-order lag, and the control laws replicated a rate-control attitude hold (RCAH) system. Using the critical tracking task, the displays have been tested in various different motion paradigms. The paradigms are designed to simulate illusory responses associated with return to a gravity-rich environment following microgravity adaptation. In a human subject experiment (N=12), we found the prototype display reduced tracking errors and improved pilot nulling performance in the various motion paradigms. Further testing is underway, focusing on the hover task in which the subject attempts to keep the vehicle from translating in response to a



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pseudo-random disturbance.

At Draper Laboratory, primary flight and situation awareness displays as well as manual flight control modes have been implemented with representative guidance, navigation, and control algorithms for piloted lunar landing. The simulation enables the transition from fully automatic to one of several manual flight control modes that have been evaluated for their ability to enable safe and precise lunar landing. The new situation awareness display enables the pilot to select a landing target based upon the range of reachable landing points, using information available from NASA's Autonomous Landing and Hazard Avoidance Technology (ALHAT) program. Several manual control modes, including a rate-control attitude hold, attitude command velocity hold with incremental position command, and vertical hold with incremental translational velocity command, have been prototyped and analyzed in simulation.

At the U.S. Army Aeromedical Research Laboratory, the dust characteristics in the UH-60 simulator's visual database have been modified to more closely resemble the attributes of lunar dust as inferred from Apollo landing videos. In addition, the cockpit of the simulator has been modified to replicate the forward window fields-of-view from the Apollo Lunar Module and our display prototype has been implemented. In the experiment (N=18), subjects use a pointer to indicate their perceived orientation (pitch and roll) and horizontal velocity (direction and magnitude) during simulated lunar landings. During each trial, subjects are provided a specific set of visual cues (i.e., eyes closed, out-the-window, or instrument displays). In addition, various intensities of simulated dust blowback were studied. Preliminary results show that dust blowback can lead to misperception of vehicle roll and pitch angles, particularly during maneuvers performed close to touchdown.

Finally, we have begun an experimental study of the effect of altered gravity on human perception of orientation. In cooperation with the National AeroSpace Training and Research (NASTAR) Center, we are using centrifuge-induced hyper-gravity as an altered gravity test-bed. In the experiment, subjects experience roll tilts at 1, 1.5, and 2 Earth Gs. Subjects report their perceptions using a somatosensory indicator, which they attempt to align with their perceived horizontal while in the dark. This technique allows us to study spatial orientation perception during dynamic roll tilts. Preliminary results indicate that while the typical overestimation characteristic of static tilt perception in hyper-gravity (G-Excess illusion) is present during dynamic tilts, sensory integration reduces the magnitude of overestimation.

Anticipated Benefits

Our goal is to determine the limits of human performance under likely extra-terrestrial landing conditions that may cause spatial disorientation. This

Organizational Responsibility

Responsible Mission Directorate:

Space Operations Mission Directorate (SOMD)

Lead Organization:

National Space Biomedical Research Institute (NSBRI)

Responsible Program:

Human Spaceflight Capabilities

Project Management

Program Director:

David K Baumann

Principal Investigator:

Laurence R Young

Co-Investigators:

Charles W Oman
Scott A Wood
Arthur Estrada
Kevin R Duda

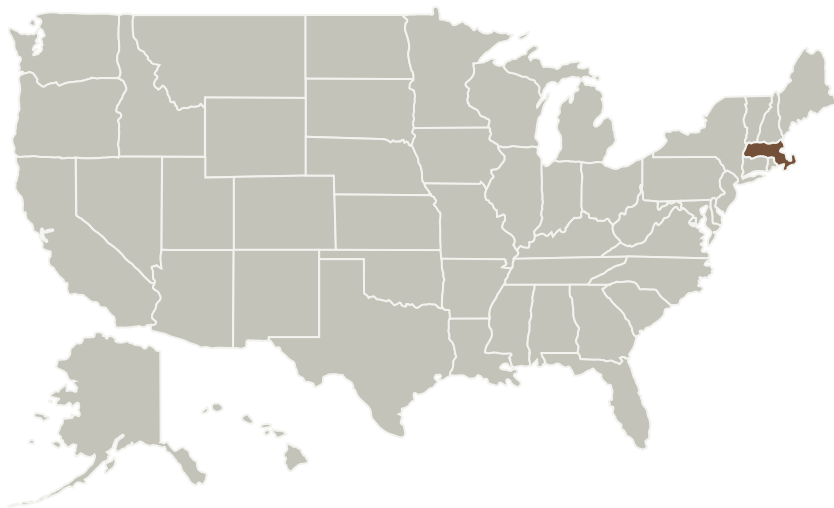
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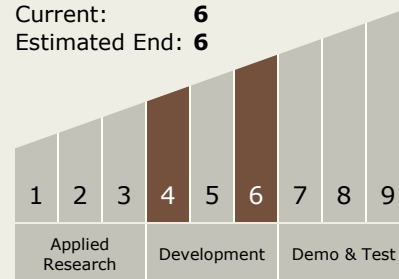
contributes to a better understanding of visual and vestibular conditions contributing to spatial disorientation during landing and the resulting effects on human manual control. We have worked on demonstrating display and control system interfaces to reduce pilot workload, improve situation awareness, and mitigate spatial disorientation to ensure a safe crewed lunar landing. Finally, the work may also have terrestrial applications in mitigating the risk of helicopter accidents by suggesting new techniques to address problems associated with brownout during landing. In particular the "achievability contour" display being prototyped may have applications in helicopter flight planning, coping with brownout, as well as mission management aspects for guiding air-drops to locations given current environmental conditions (e.g., wind, air density). This display concept can be used for any energy-constrained terrestrial approach or landing. The Observer vestibular-visual spatial orientation model has been used to predict astronaut perceptions during lunar landing motions. This work in applying this model to vehicle trajectories has applications for terrestrial vehicles as well. The vehicle motions experienced during terrestrial accidents can be simulated in the model to determine if spatial disorientation may have played a role. Advances in the understanding of the role of motion cues and visual surround will contribute to aviator training relevant to spatial disorientation.

Primary U.S. Work Locations and Key Partners



Technology Maturity (TRL)

Start: **4**
Current: **6**
Estimated End: **6**



Technology Areas

Primary:

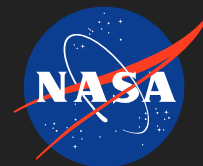
- TX06 Human Health, Life Support, and Habitation Systems
 - └ TX06.6 Human Systems Integration
 - └ TX06.6.1 Human Factors Engineering

Target Destinations

The Moon, Mars

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| Organizations Performing Work | Role | Type | Location |
|---|-------------------------|---------------|--------------------------|
| National Space Biomedical Research Institute(NSBRI) | Lead Organization | Industry | Houston, Texas |
| Army Aeromedical Research Laboratory | Supporting Organization | US Government | Fort Rucker, Alabama |
| Massachusetts Institute of Technology(MIT) | Supporting Organization | Academia | Cambridge, Massachusetts |
| The Charles Stark Draper Laboratory, Inc. | Supporting Organization | R&D Center | Cambridge, Massachusetts |

Primary U.S. Work Locations

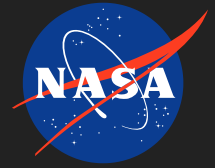
Massachusetts

Project Transitions

July 2008: Project Start

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✓ September 2012: Closed out

Closeout Summary: In the previous year, we have performed three separate experiments. At NASA JSC, the tilt-translation sled (TTS) was used to study the effect of our advanced countermeasure prototype display on manual control piloting performance. Performance was measured in a series of different motion paradigms designed to provide motion cues as might be experienced by a microgravity adapted astronaut flying a lunar lander vehicle. First a "critical tracking task" was studied in which the pilot attempted to keep an unstable vehicle upright. Next a "hover task" was studied in which the pilot attempted to keep the vehicle at a fixed horizontal position. Both of the tasks were done only in the pitch/fore-aft direction. A human subject experiment was performed in which manual control performance was consistently greater with the prototype display, with > 70% reduction in root-mean-square error. At the U.S. Army Aeromedical Research Laboratory, the UH-60 helicopter simulator was utilized to study the effect of lunar dust blowback on pilot perceptions of vehicle orientation during the final stages of landing. The dust characteristics in the visual database were modified to more closely resemble the attributes of lunar dust inferred from Apollo landing videos and the cockpit was modified to mimic the forward window fields-of-view from the Apollo Lunar Module. In the experiment subjects reported their perceived orientation (pitch and roll) and horizontal velocity (direction and magnitude) during simulated lunar landings. Different levels of dust blowback were simulated and compared to cases where the subject had no visual cues or when the subject was provided an instrument display. Subjects often misperceived their orientation during landings, particularly when dust blowback obscured visual out-the-window cues. Finally, we have begun an experimental study of the effect of gravity on human perception of orientation. In cooperation with the National AeroSpace Training and Research (NASTAR) Center, we are using centrifuge-induced hyper-gravity as an altered gravity test-bed. In the experiment, subjects report their perceived orientation during roll tilts presented at 1, 1.5, and 2 Earth Gs. The roll tilts are presented over a range of angles and rotation rates or frequencies. Subjects report their perceptions using a somatosensory indicator, which they attempt to align with their perceived horizontal while in the dark. This technique allows us to study spatial orientation perception during dynamic roll tilts. Preliminary results indicate that while the typical overestimation characteristic of static tilt perception in hyper-gravity (G-Excess illusion) is present during dynamic tilts, sensory integration reduces the magnitude of overestimation. This is important in understanding how the altered gravity levels experienced during space exploration missions may impact astronaut perceptions of vehicle orientation.

Stories

Abstracts for Journals and Proceedings
(<https://techport.nasa.gov/file/53895>)

Abstracts for Journals and Proceedings
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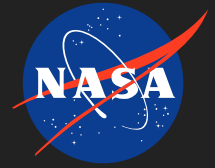
Dissertations and Theses
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Papers from Meeting Proceedings
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Papers from Meeting Proceedings
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Papers from Meeting Proceedings
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Papers from Meeting Proceedings
(<https://techport.nasa.gov/file/53929>)

Papers from Meeting Proceedings
(<https://techport.nasa.gov/file/53926>)

Project Website:

<https://taskbook.nasaprs.com>